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SUBMISSION OF SUBSTITUTE SPECIFICATION

Sir:

This Submission of Substitute Specification includes a clean copy of the Specification in compliance with 37 C.F.R. 1.52, 1.121(b)(3), and 1.125. No new matter has been added.

Respectfully submitted,

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ELECTRIC POWER STEERING APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to an electric power
5 steering apparatus for applying an assisting steering
force to a steering mechanism of a vehicle by driving an
electric motor according to the operation for steering the
vehicle. More particularly, the present invention relates
to a convergence control for returning a steering wheel to
10 a neutral position in the electric power steering
apparatus.

Conventionally, there is provided an electric power
steering apparatus in which an assisting steering force is
15 applied to a steering mechanism by driving an electric
motor according to a steering torque given to a handle
(steering wheel) by a driver. In this electric power
steering apparatus, there is provided a torque sensor by
which a steering torque given to the steering wheel (a
20 steering unit) is detected. According to the steering
torque detected by the torque sensor, an electric current
command value is set as a target value of the electric
current which is made to flow in the electric motor.
According to the deviation between this electric current
25 command value and the electric current value actually

flowing in the electric motor, a voltage command value to be given to a drive unit of the electric motor is generated. For example, the drive unit for driving the electric motor includes: a PWM signal generation circuit for generating a pulse width modulation signal (PWM signal) of a duty ratio according to the voltage command value; and a motor drive circuit composed of a power transistor which is turned on and off according to the duty ratio of the PWM signal. Voltage corresponding to the duty ratio, that is, voltage corresponding to the voltage command value is impressed upon the electric motor. An electric current flowing in the electric motor by this impression of voltage is detected by the electric current detector, and a difference between this detection value and the above electric current command value is used as deviation for generating the above voltage command value. As described above, in the electric power steering apparatus, feedback control is executed so that the target electric current (the electric current command value) which is set according to the steering torque can flow in the electric motor.

In the above electric power steering apparatus, convergence control is also executed for converging the steering wheel (a steering unit for steering the vehicle)

to the neutral position. This convergence control is

executed by correcting the target value of the motor

current according to the steering speed and the running

speed of the vehicle. In this case, the quantity of

5 correction is referred to as "a convergence electric

current value" or "a damping compensation electric current

value". A specific method of this convergence control is

described as follows. For example, a damping compensation

electric current map, which is a table for giving a

10 relation between the damping compensation electric current

and the steering speed, is previously prepared, and a

vehicle speed gain map, which is a table for giving a

relation between the gain to be multiplied by the damping

compensation electric current value and the vehicle speed,

15 is previously prepared. According to these maps, the

steering speed at each point of time and the damping

compensation electric current value according to the

vehicle speed are determined.

20 As described above, in the conventional convergence

control, the damping compensation electric current is set

according to the steering speed and the vehicle speed.

Therefore, even when no convergence control is required,

the motor current is corrected according to the damping

25 compensation electric current. For example, when the

steering wheel is quickly rotated, that is, in the case of a quick steering operation, a driver feels steering

operation of the steering wheel heavy due to convergence control. In other words, the correction of a motor

current in the case of convergence control corresponds to

the generation of torque in a direction opposite to the

rotating direction of the steering wheel. Therefore,

convergence control affects a driver's feeling of

steering.

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SUMMARY OF THE INVENTION

It is an object of the present invention to provide

an electric power steering apparatus in which a driver's

feeling of steering is enhanced by preventing convergence

15 control from affecting a driver's feeling of steering

while an excellent convergence characteristic is being

ensured.

In order to solve the aforesaid object, the invention

is characterized by having the following arrangement.

20 Aspect 1: An electric power steering apparatus for

applying an assisting steering force to a steering

mechanism of a vehicle by driving an electric motor

according to a steering operation performed by a steering

unit for steering the vehicle, comprising:

an electric current command value calculation unit which calculates an electric current command value by correcting a target value of an electric current to be made to flow in the electric motor;

5 a drive control unit which controls the drive of the electric motor so that an electric current of the electric

current command value flows in the electric motor; and

a convergence control unit which determines a damping

compensation value, which is a correction value of the

10 target value to be corrected by the electric current

command value calculation unit, so that a quantity of

steering operation performed by the steering unit is

converged to a neutral point, the convergence control unit

including:

15 a compensation electric current setting unit

which determines a basic damping compensation electric current

value corresponding to the correction value of the target

value based on a steering speed which is a changing speed

of the quantity of the steering operation and a vehicle

20 speed, and

a compensation electric current adjusting unit

which which adjusts the basic damping compensation

electric current value based on the steering torque given

to the steering unit and the quantity of the steering

operation, thereby calculating the damping compensation value.

Aspect 2. The electric power steering apparatus according

15 to the aspect 1, wherein the compensation electric current

adjusting unit adjusts the basic damping compensation

electric current value so that the damping compensation

value is increased when the quantity of steering operation

increases more than the neutral point and then decreases

10 in a predetermined period of time and the steering torque

is not higher than a predetermined value.

Aspect 3. The electric power steering apparatus according

to the aspect 2, wherein the compensation electric current

15 adjusting unit including:

a gain deciding unit which decides a gain with

respect to the basic damping compensation electric current

value based on the quantity of operation and the steering

torque, and

20 a multiplication unit which multiplies the basic

damping compensation electric current value by the gain,

thereby calculating the damping compensation value, and

wherein the gain deciding unit increases the gain

when the quantity of operation increases more than the

neutral point and decreases and the steering torque is not higher than a predetermined value.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Fig. 1 is a schematic illustration showing the constitution of an electric power steering apparatus of an embodiment of the present invention together with the constitution of a vehicle.

Fig. 2 is a block diagram showing a hardware constitution of ECU which is a control unit of the electric power steering apparatus of the above embodiment.

Fig. 3 is a block diagram showing a functional constitution of a motor control section of the electric power steering apparatus of the above embodiment.

15 Fig. 4 is a block diagram showing a functional constitution of a convergence control section in the motor control section of the above embodiment.

Fig. 5A and 5B are flow charts showing the motor control processing in the above embodiment.

20 Fig. 6A and 6B are flow charts showing convergence control processing included in the motor control processing in the above embodiment.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to the accompanying drawings, embodiments of the present invention will be explained as follows.

1. OVERALL CONSTITUTION

Fig. 1 is a schematic illustration showing the constitution of an electric power steering apparatus according to the first embodiment of the present invention together with the constitution of a vehicle. This electric power steering apparatus includes: a steering shaft 102, one end of which is fixed to the handle (steering wheel) 100 (a steering unit); a rack pinion mechanism 104 connected with the other end of the steering shaft 102; a steering angle sensor 2 for detecting a steering angle of the steering wheel 100; a torque sensor 3 for detecting a steering torque given to the steering shaft 102 by the operation of the steering wheel 100; an electric motor 6 for generating an assisting steering force so as to reduce a load given to a driver when the steering wheel is operated; a reduction gear 7 for transmitting an assisting steering force generated by the motor 6 to the steering shaft 102; and an electronic control unit (ECU) 5 for controlling the drive of the motor 6 according to the sensor signals sent from the steering angle sensor 2, the torque sensor 3 and the vehicle speed sensor 4. Electric power is supplied to the

electronic control unit (ECU) 5 from the battery 8 mounted on the vehicle via the ignition switch 9. When a driver

operates the steering wheel 100 in a vehicle on which the electric power steering apparatus is mounted, the steering

torque given by the steering operation is detected by the

torque sensor 3, and the electric motor 6 is driven by ECU

5 according to the steering torque detected by the

steering torque sensor 3, the vehicle speed detected by

the vehicle speed sensor 4 and the steering angle detected

by the steering angle sensor 2. Due to the foregoing, the

motor 6 generates an assisting steering force. When this

assisting steering force is given to the steering shaft

102 via the reduction gear 7, a steering load given to the

driver can be reduced. That is, a sum of the steering

torque given by the steering operation, and the torque

generated by the assisting steering force generated by the

motor 6 is given to the rack pinion mechanism 104 via the

steering shaft 102 as the output torque. When the pinion

shaft is rotated by this output torque, the rotation is

converted into a reciprocating motion of the rack shaft by

the rack pinion mechanism 104. Both end portions of the

rack shaft are connected with the wheels 108 via the

connecting members 106 constituted by the tie rods and

knuckle arms. Therefore, according to the reciprocating

motion of the rack shaft, the directions of the wheels 108 can be changed.

2. CONSTITUTION OF CONTROL UNIT

Fig. 2 is a block diagram showing a hardware constitution of ECU 5 functioning as a control unit of the above electric power steering apparatus. This ECU 5 includes: a microcomputer 10 in which the timer function is built; a PWM signal generating circuit 32; a motor drive circuit 34; an electric current detector 36; and a voltage detector 37. Into the microcomputer 10, the steering angle signal θ is inputted from the steering angle sensor 2, the steering torque signal T_s is inputted from the torque sensor 3, and the vehicle speed signal V_{sw} is inputted from the vehicle speed sensor 4. In this ECU 5, the electric current detector 36 detects an electric current supplied to the motor 6, that is, the electric torque motor current. The electric current detector 36 detects a motor current, and the detection result is outputted as the electric current detection value I_m . The voltage detector 37 detects a voltage between the terminals of the motor 6, and the detection result is outputted as the voltage detection value V_m . The electric current detection value I_m and the voltage detection value V_m are also inputted into the microcomputer 10. When the microcomputer 10 executes a

program stored in the internal memory, it functions as a motor control section. The voltage command value V_d , which is a voltage value to be impressed upon the motor 6,

is calculated so that the motor 6 can generate an appropriate assisting steering torque corresponding to the steering torque and the vehicle speed according to the steering angle signal θ , steering torque signal T_s , vehicle speed V_s , electric current detection value I_m and

voltage detection value V_m . The PWM signal generation circuit 32 generates a PWM signal, the duty ratio of which changes according to the voltage command value V_d and

supplies the signal to the motor drive circuit 34. The motor drive circuit 34 is constituted by a plurality of power transistors as the switching elements. These

switching elements are turned on and off in response to the PWM signal generated in the PWM signal generation

circuit 32. Due to the foregoing, the motor drive circuit 34 generates a voltage according to the voltage command value V_d and impresses the voltage upon the motor 6.

Fig. 3 is a block diagram showing a functional constitution of the motor control section (microcomputer) 10 in the above ECU. This motor control section 10 includes: an assisting electric current setting section 12; a steering angle restricting control section 14; an

adder 16; a differentiator 18; a convergence control section 20; an electric current command value calculating section 22; a subtracter 24; and a control calculating section 30. These components are realized by software when the microcomputer 10 executes a predetermined program.

In the above motor control section 10, the steering torque signal T_s outputted from the torque sensor 3 is inputted into the assisting electric current setting section 12, the steering angle restricting section 14 and the convergence control section 20. The vehicle speed signal V_s outputted from the vehicle speed sensor 4 is inputted into the assisting electric current setting section 12, the steering angle restricting section 14 and the convergence control section 20. The steering angle signal θ outputted from the steering angle sensor 2 is inputted into the steering angle restricting section 14, the differentiator 18 and the convergence control section 20. When the differentiator 18 conducts time-differentiation on the steering angle signal θ so as to calculate the steering speed ω , the steering speed ω is calculated. The thus obtained steering speed ω is inputted into the convergence control section 20.

The assisting electric current setting section 12

calculates the assisting electric current value I_a , which

is an electric current value to be supplied to the motor 6

so as to generate an appropriate assisting steering force,

according to the steering torque T_s and the vehicle speed

signal V_s .

The steering angle restricting control section 14

calculates the steering angle restricting electric current

value I_{ss} as a quantity of correction with respect to the

assisting electric current value I_a for preventing the

steering wheel 100 from being excessively rotated in the

case where a driver promptly operates the steering wheel

100 for the purpose of evading a collision with an

obstacle on a road when the vehicle is running at a high

speed. The steering angle restricting control section 14

determines a quantity of steering angle, which is an

appropriate quantity of steering wheel operation (which

will be referred to as "an appropriate quantity of

steering angle"), according to the vehicle speed on the

basis of the vehicle speed signal V_s . In the case where

the actual quantity of steering angle of the steering

wheel 100 exceeds an upper limit of the appropriate

quantity of steering angle according to the steering angle

signal θ , the steering angle restricting electric current

value I_{ss} is decided to correct the assisting electric current value I_a so that the assisting steering can be gradually reduced or the motor 6 can generate a steering force in the opposite direction to the steering direction.

5

When the steering angle restricting electric current value I_{ss} decided above is added to the assisting electric current I_a by the adder 16, the electric current target value I_t , which is an assisting electric current after correction, can be obtained. This electric current target value I_t is inputted into the electric current command value calculating section 22.

The convergence control section 20 decides the damping compensation electric current value, which will be referred to as "a damping compensation value" hereinafter, as a quantity of correction (subtracted value) with respect to the electric current target value I_t so that the steering wheel 100 can be converged to the neutral position according to the steering speed ω , the vehicle speed signal V_s , the steering angle signal θ and the steering torque signal T_s . The convergence control section 20 in this embodiment decides the damping compensation value I_{dc} for convergence control while consideration is given to not only the steering speed and

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the vehicle speed but also the steering angle and the steering torque. From this viewpoint, the convergence control of this embodiment is different from the conventional convergence control. The detail of the

method of deciding the damping compensation value I_{dc} will be described later.

The thus decided damping compensation value I_{dc} is

inputted into the electric current command value calculating section 22. The other compensation electric

current values such as an inertia compensation electric current value is also calculated by the motor control

section 10 and inputted into the electric current command value calculating section 22. The electric current

command value calculating section 22 corrects the electric current target value I_t according to the damping

compensation value I_{dc} and the other compensation values and outputs the corrected electric current target value as

the electric current command value I_d .

The motor 6 is controlled as follows by the drive

control unit constituted by the subtracter 24, control calculating section 30, PWM signal generating circuit 32, motor drive circuit 34 and electric current detector 36

according to this electric current command value I_d .

The subtracter 24 calculates the deviation ($\Delta I = I_d - I_m$) between the electric current command value I_d (the

electric current target value after correction) outputted

5 from the electric current command value calculating

section 22, and the electric current detection value I_m

outputted from the electric current detector 36 as an

actual motor current. This deviation ΔI is inputted into

the control calculating section 30. The control

10 calculating section 30 calculates the voltage command

value V_d by the control calculation (usually, proportional

integral calculation) according to the above deviation ΔI .

This voltage command value V_d is outputted

from the microcomputer 10 which is a motor control

15 section. The voltage command value V_d outputted from the

microcomputer 10 is inputted into the PWM signal

generation circuit 32. In the PWM signal generation

circuit 32, the PWM signal, the duty ratio of which is

according to the voltage command value V_d , is generated.

20 When the switching element in the motor drive circuit 34

is turned on and off by the PWM signal, a voltage

according to the voltage command value V_d is generated,

and this voltage is impressed upon the motor 6. An

electric current flows in the motor 6 by this voltage

25 impression, and the motor 6 generates a torque according

to this electric current. At this time, the motor current is detected by the electric current detector 36, and the electric current detection value I_m as the detection

result is used for calculating the above deviation $\Delta I = I_d - I_m$. In this way, feedback control is conducted so that a target electric current, which is equal to the electric current command value (electric current target value after correction) I_d calculated by the motor control section

(microcomputer 10), can flow in the motor 6.

Fig. 3 is a block diagram showing a constitution of the motor control section 10.

Fig. 4 is a block diagram showing a constitution of the convergence control section 20.

Fig. 5 is a block diagram showing a constitution of the steering speed detecting section 30.

Fig. 6 is a block diagram showing a constitution of the vehicle speed detecting section 40.

Fig. 7 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 50.

Fig. 8 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 60.

Fig. 9 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 70.

Fig. 10 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 80.

Fig. 11 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 90.

Fig. 12 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 100.

Fig. 13 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 110.

Fig. 14 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 120.

Fig. 15 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 130.

Fig. 16 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 140.

Fig. 17 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 150.

Fig. 18 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 160.

Fig. 19 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 170.

Fig. 20 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 180.

Fig. 21 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 190.

Fig. 22 is a block diagram showing a constitution of the steering speed and vehicle speed detecting section 200.

value is referred to as "a basic damping compensation electric current value" and represented by the mark "Idco"

so that this damping compensation electric current value can be distinguished from the damping compensation value

5 Idc outputted from the convergence control section 20.

The gain deciding section 204 for each steering condition decides the damping compensation electric

current gain Gc according to the steering state on the

10 basis of the steering angle signal θ and the steering torque signal Ts. The detail of the method of deciding

this damping compensation electric current gain Gc will be described later.

15 The basic damping compensation electric current value

Idco and the damping compensation electric current gain Gc decided as described above are inputted into the

multiplier 206, and the multiplier 206 calculates the

multiplied value $Gc \times Idco$. This multiplied value $Gc \times Idco$

20 Idco is outputted from the convergence control section 20

as the damping compensation value Idc and used for

correcting the electric current target value It in the

electric current command value calculating section 22 so

as to find the electric current command value Id.

4. MOTOR CONTROL PROCESSING

In this embodiment, the motor control section having

the above constitution is realized by software when the

microcomputer 10 executes a predetermined program, that

is, when the processing shown in Figs. 5 and 6, which will

be referred to as "motor control processing" hereinafter,

is executed. This motor control processing will be

explained as follows.

In this embodiment, when the ignition switch 9 is

turned on, the microcomputer 10 in ECU 5 initializes a

variable and flag used in the motor control processing as

shown in Fig. 5A (step 12). In this initializing process,

the first gain value G1 is set as the damping compensation

electric current gain Gc, and the flag Flg used for

detecting the specific steering state described later is

reset (Flg = 0). In this case, the first gain value G1 is

a predetermined value to be set as the damping compensation

electric current gain Gc in the case where

the steering state is not a specific steering state.

Therefore, the first gain value G1 is set so that the

damping compensation electric current value Idc be lower

than the conventional one. In this connection, the second

gain value G2 described later is a predetermined value to

be set as the damping compensation electric current gain

Gc in the case where the steering state is a specific steering state. The second gain value G2 is set so that the damping compensation electric current value Idc be higher than the conventional one in the specific steering state.

Next, the microcomputer 10 receives the steering torque signal Ts from the torque sensor 3 and receives the vehicle speed signal Vs from the vehicle speed sensor 4 (step S14, S16). In the following explanations, the value of the thus received steering torque signal Ts is referred to as a steering torque detection value represented by the mark "Ts". The value of the thus received vehicle speed signal Vs is referred to as a vehicle speed detection value represented by the mark "Vs". Successively, the microcomputer 10 receives the electric current detection value Im from the electric current detector 36 (step S18). After that, when the microcomputer 10 conducts differential-calculus on the steering angle signal θ sent from the steering angle sensor 2, the steering speed ω is found (step S20).

Next, when the microcomputer 10 executes the target electric current setting processing shown in Fig. 5B, the electric current command value Id is calculated (step

S22). In this target electric current setting processing, the microcomputer 10 operates as follows.

First, according to the steering torque detection value T_s and the vehicle speed detection value V_s , the assisting electric current value I_a is decided (step S32). Specifically, the assisting electric current value I_a is decided as follows. A table (referred to as "an assisting

table"); on which a relation between the value of an assisting electric current to be supplied to the motor 6 for generating an appropriate assisting steering force and the steering torque is shown by using the vehicle speed as a parameter, is previously stored in the memory of the microcomputer 10, and the assisting electric current value I_a is decided by referring to this assisting table.

Next, the steering angle restricting processing is executed which is a processing for restricting a quantity of the steering angle so that a quantity of the steering angle of the steering wheel 100 (absolute value $|\theta|$ of the steering angle detection value θ) can be an appropriate value (step S34). In this steering angle restricting processing, first, an appropriate quantity of the steering angle is decided according to the vehicle speed detection value V_s . Next, it is judged whether or not the actual

quantity $|\theta|$ of the steering angle of the steering wheel 100 exceeds the upper limit of the appropriate quantity of the steering angle. In the case where the actual quantity $|\theta|$ of the steering angle of the steering wheel 100 exceeds the upper limit of the appropriate quantity of the steering angle, the steering angle restricting electric current value I_{ss} is decided to correct the assisting electric current value I_a so that the assisting steering force can be gradually decreased or a steering force in the opposite direction to the steering direction can be generated by the motor 6 according to the steering torque T_s and the steering angle detection value θ . For example, by a map previously prepared, according to the vehicle speed and the steering angle, a quantity of decrease in the assisting steering force or the steering angle restricting electric current value I_{ss} , which corresponds to a steering force in the opposite direction, is decided. When the steering angle restricting electric current value I_{ss} is added to the assisting electric current value I_a described above, (the assisting electric current value I_a , which has been subjected to the steering angle restricting processing) + (I_{ss}) is obtained as the electric current target value I_t .

When the assisting electric current I_a is corrected by the steering angle restricting processing as described above, it is possible to avoid the occurrence of a case in which a driver excessively rotates the steering wheel to cope with the external circumstances (for example, a driver excessively rotates the steering wheel to avoid a collision with an obstacle on a road). In this connection, in the steering angle restricting processing, the steering restricting electric current value I_{ss} is calculated according to not only the steering angle detection value θ but also the steering torque detection value T_s . The reason is to prevent the steering wheel from being obstructed while an operation, which is necessary for avoiding a collision with an obstacle, from being obstructed while an unnecessary increase in the quantity of the steering angle is being prevented. Accordingly, in this steering angle restricting processing, even when the actual quantity $|\theta|$ of the steering angle of the steering wheel exceeds the upper limit of the appropriate quantity of the steering angle, in the case where the steering torque is not less than a predetermined value, the steering angle restricting electric current value I_{ss} is calculated as a value, the absolute value of which is low. As a result, a quantity of the correction of the assisting electric current value I_a becomes low. Therefore, the vehicle can

stably run at high speed without hurting the driver's good feeling of steering.

After the above steering angle restricting processing

5 is completed, the convergence control processing is

executed which is a processing for converging the quantity

of the steering angle of the steering wheel 100 to the

neutral point (step S36). In this case, at the neutral

point, the quantity of the steering angle is usually 0,

10 corresponding to the straight running of the vehicle.

Fig. 6A is a flow chart showing this convergence control

processing.

In this convergence control processing, first, the

15 basic damping compensation electric current value I_{dco} is

calculated by the same damping compensation electric

current calculation as the conventional one (step S52).

Specifically, a damping compensation electric current map,

on which a relation between the vehicle speed and the

20 basic damping compensation electric current value is shown

by using the steering speed as a parameter, is previously

stored in the memory built in the microcomputer 10, and

when the map is referred, the basic damping compensation

electric current value I_{dco} corresponding to the steering

25 speed ω , which is calculated in step S20, and also

corresponding to the vehicle speed detection value V_s ,

which is inputted in step S16, may be decided. Instead of

the above method, the following method may be adopted. A

damping compensation electric current map, which gives a

5 relation between the steering speed and the damping

compensation electric current value, and a vehicle speed

gain map, which gives a relation between the gain to be

multiplied by the damping compensation electric current

value and the vehicle speed, are previously stored in the

10 memory built in the microcomputer 10. First, when the

damping compensation electric current map is referred, a

damping compensation electric current value according to

the above steering speed ω is decided. Next, when the

vehicle speed gain map is referred, a gain according to

15 the vehicle speed detection value V_s is decided. When the

damping compensation electric current value and the gain

are multiplied to each other, the basic damping

compensation electric current value I_{dc} may be decided.

In this connection, setting is conducted in such a manner

20 that the basic damping compensation electric current value

I_{dc} is increased according to an increase in the vehicle

speed V_s and also according to an increase in the steering

speed ω .

After the basic damping compensation electric current value I_{dc0} has been decided as described above, next, the gain deciding processing for deciding the damping compensation electric current gain G_c to be multiplied by this basic damping compensation electric current value I_{dc0} is executed (step S54).

In this gain deciding processing, the quantity $|\theta|$ of steering angle is increased from the neutral point in the predetermined period of time T_{m0} and then decreased. Further, a state in which the steering torque detection value T_s is not more than the predetermined value T_{s0} is detected as a specific steering state. In this specific steering state, the damping compensation electric current gain G_c is set at the second gain value G_2 which is a high value. In a normal steering state except for this specific steering state, the damping compensation electric current gain G_c is set at the first gain value G_1 ($G_1 < G_2$) which is a relatively low value. In this case, the above predetermined period of time T_{m0} is a sufficiently short period of time compared with the period of time in which a driver (human) operates the steering wheel so that the quantity of steering angle can be increased from the neutral point and then decreased. For example, the above predetermined period of time T_{m0} is approximately 500 msec

to 1 sec. The above predetermined period of time is a value which is set at a reference value for judging whether or not the driver (human) operates the steering wheel 100 so as to steer the wheels 108.

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The above specific steering state corresponds to a state in which convergence control is required. For example, the above specific steering state corresponds to

a state in which the steering wheel is suddenly returned to a normal state when a wheel (tire) comes into a hole made on a road surface in the case of running at high speed. If convergence control is not sufficiently conducted in the above steering state,

a change in the steering angle (steering motion) is extended and the vehicle may behave dangerously. In this

embodiment, by the gain deciding processing, in the above specific steering state, compared with a normal steering

state, the damping compensation electric current gain G_c becomes a sufficiently high value G_2 (for example, a value 1.5 times as high as the first gain value G_1). Due to the

foregoing, convergence control can be sufficiently conducted. Referring to Fig. 6B, an example of the gain deciding processing will be explained below.

In the gain deciding processing shown in Fig. 6B, the

25 microcomputer 10 operates as follows.

First, according to the steering angle detection value θ , it is judged whether or not the steering angle quantity $|\theta|$ is increased from the neutral point (step

S62). In the case where the steering angle quantity $|\theta|$ is increased from the neutral point as a result of the judgment; the timer built in the microcomputer 10 is reset and then started (step S64). The flag Flg is set (Flg = 1) (step S66). After that, the program proceeds to step

S68. On the other hand, in the case where the steering angle quantity $|\theta|$ is not increased from the neutral point; the program proceeds to step S68 as it is.

In step S68, it is judged whether or not the steering torque detection value T_s is not more than the predetermined value T_{s0} . When $T_s > T_{s0}$ as a result of the judgment, the Flag Flg is reset to show that the steering wheel is operated by the driver (Flg = 0) (step S70).

After that, the program proceeds to step S72. When $T_s < T_{s0}$ as a result of the judgment, the program proceeds to step S72 as it is.

In step S72, according to the steering angle detection value θ , it is judged whether or not the steering angle quantity $|\theta|$ is decreased. In the case where the steering angle quantity $|\theta|$ is decreased as a

result of the judgment, the program proceeds to step S74.

In the case where the steering angle quantity $|\theta|$ is not decreased as a result of the judgment, the program returns to the routine of convergence control processing.

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In step S74, it is judged whether or not the value T_m of the timer built in the microcomputer 10 is not more

than the predetermined period of time T_{m0} . When $T_m \leq T_{m0}$

as a result of the judgment, the program proceeds to step S76. When $T_m > T_{m0}$, the damping compensation electric

current gain G_c is set at the first gain G_1 (step S80),

and the program returns to the convergence control

processing routine.

15 In step S76, it is judged whether or not the flag Flg is set ($Flg = 1$ or not). When the flag Flg is set ($Flg = 1$) as a result of the judgment, that is, when the steering

torque detection value T_s does not exceed the predetermined value T_{s0} after the point of time of the

20 latest start of the timer, the damping compensation

electric current gain G_c is set at the second gain value

G_2 which is higher than the first gain value G_1 (step S78), and the program returns to the convergence control

processing routine. On the other hand, as a result of the

25 judgment, when the flag Flg is reset ($Flg = 0$), that is,

in the case where the steering torque detection value T_s exceeds the predetermined value T_{s0} after the point of time of the latest start of the timer, the damping compensation electric current gain G_c is set at the first gain value G_1 (step S78), and the program returns to the convergence control processing routine.

When the program returns from the above gain deciding processing routine to the convergence control processing routine, when the basic damping compensation electric current value I_{dc0} is multiplied by the damping compensation electric current gain G_c at this point of time, the damping compensation value I_{dc} is calculated (step S56 in Fig. 6A). After that, the program returns to the routine of the target electric current setting processing.

After the program has returned from the convergence control processing routine to the target electric current setting processing routine, when the electric current target value I_t is corrected according to the damping compensation value I_{dc} , which is obtained by the convergence control processing, and also according to the other compensation electric current values, the electric current command value I_d is calculated (step S38 in Fig.

5B). After that, the program returns to the main routine shown in Fig. 5A.

When the program returns from the target electric current setting processing routine to the main routine, the deviation $\Delta I = I_d - I_m$ between the electric current command value I_d and the electric current detection value I_m outputted from the electric current detector 36 is calculated, and the voltage command value V_d is calculated by the feedback control calculation (usually, proportional and integral calculation) according to this deviation ΔI (step S24). Then, this voltage command value V_d is outputted from the microcomputer 10 which is a motor control section (step S26 in Fig. 5A). After that, the program returns to step S14. After that, the above steps S14 to S26 are repeated until the ignition switch 9 is turned off.

As can be understood from the motion (motor control processing) of the microcomputer 10, the convergence control of the control section 20 (shown in Fig. 3) in the motor control section can be realized by the convergence control processing (shown by step S36 in Fig. 5B and Fig. 6A), and the gain deciding section 204 for each steering condition (shown in Fig. 4), which is a component of the convergence

control section 20, can be realized by the gain deciding processing (step S54 in Fig. 6A and Fig. 6B).

5. EFFECT

According to the present embodiment described above, in the gain deciding processing, especially in the step S54, the gain is decided for a specific steering state in which the convergence control is especially required, that is, in a state in which the steering angle quantity $|\theta|$ is increased from the neutral point and then decreased in the predetermined period of time $Tm0$ and further the steering torque detection value Ts is not more than the predetermined value $Ts0$; the damping compensation electric current gain Gc is set at the second gain value $G2$ higher than the first gain value $G1$ (step S78 in Fig. 6A and Fig. 6B). On the other hand, in the normal steering state except for the above specific steering state, the damping compensation electric current gain Gc is set at the first gain value $G1$ which is a relatively low value (step S80). In the above specific steering state in which the convergence control is especially required according to the steering angle detection value θ and the steering torque detection value Ts , for example, in the case of a phenomenon in which the wheel 108 comes into a hole when the vehicle is running at high speed, and the steering wheel is promptly returned, the damping compensation

electric current gain G_c is increased. Therefore, the convergence property of the steering wheel 100 to the neutral position is enhanced as compared with the convergence property of the conventional apparatus. On

5 the other hand, in the normal steering state, an intensity of the damping compensation electric current gain G_c becomes lower than that of the conventional apparatus, so that the damping compensation value I_{dc} can be suppressed.

Therefore, a bad influence of the convergence control on the driver's feeling of steering can be avoided. Accordingly, it is possible to obtain a driver's good feeling of steering. In this connection, even in the

normal steering state, although the damping compensation value I_{dc} is lower than that of the conventional apparatus, the convergence control is executed.

Therefore, for example, when the vehicle changes a lane while it is running at high speed, the vehicle behavior can be stabilized.

As described above, according to the present embodiment, in the normal steering state, while the convergence control is being suppressed as compared

20 with the conventional apparatus, the convergence control is sufficiently conducted when necessary. Accordingly, enhancement of the convergence property to the neutral position of the steering wheel and enhancement of a

driver's feeling of steering can be simultaneously accomplished.

6. VARIATION

5 In the above embodiment, the steering angle quantity $|\theta|$ is increased from the neutral point and then decreased in the predetermined period of time T_{m0} , and further the steering angle quantity $|\theta|$ is not more than the predetermined value T_{s0} is detected as a specific steering state in which the convergence control is especially required, that is, the state is detected as a steering state in which the damping compensation electric current gain G_c should be set at a higher value G_2 (shown in step S78 in Fig. 6B). However, as the detecting condition of this specific steering state, the condition that the steering angle quantity $|\theta|$ is not more than a predetermined value (for example, $|\theta| \leq 45^\circ$) may be added. The detecting condition of detecting the specific steering state, in which the damping compensation electric current gain G_c is increased, is not limited to the above condition. As long as the condition is to detect a steering state, in which the convergence control is required when the wheel (tire) is twisted being affected by the state of a road, according to the steering torque detection value T_s and the steering angle detection value

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θ , any condition different from the condition of the above embodiment may be adopted.

In the above embodiment, when the steering angle

signal θ inputted from the steering angle sensor 2 into the microcomputer 10 is differentiated, the steering speed ω corresponding to the actual steering speed is calculated (shown in Fig. 3). However, instead of that, the steering speed ω may be calculated according to the voltage V_m (voltage between the terminals of the motor 6) inputted from the voltage detector 37. Further, instead of that, a sensor for detecting the rotating angle of the motor 6 may be provided, and the steering speed ω may be calculated according to a changing speed of the rotating angle.